Renewable and Sustainable Energy Reviews 16 (2012) 6497–6506

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy autonomy in sustainable communities—A review of key issues

Callum Rae, Fiona Bradley *

Department of Architecture, University of Strathclyde, 131 Rottenrow, Glasgow, G4 0NG, Scotland, UK

ARTICLE INFO

Article history:
Received 21 June 2012
Accepted 4 August 2012
Available online 27 September 2012

Keywords:
Energy autonomy
Sustainable communities
Renewable energy

ABSTRACT

Recent years have seen the successful development and deployment of a range of small scale renewable energy systems. Driven in part by improving technical capability and by ambitious carbon emissions reduction targets, there has been the beginning of a shift towards a more distributed energy generation model, capable of delivering a range of potential benefits, but also presenting a number of social and technical challenges.

One area of society where the benefits can be seen as being both highly applicable and highly relevant is at the community level and at this scale in particular, increased levels of energy autonomy can deliver a host of social, financial and environmental benefits. Therefore, the concept of energy autonomy is widely regarded as an effective tool in the push towards sustainable development, with 'sustainable communities' often highlighted as particularly relevant for applying its principles.

Given its significance and its broad interdisciplinary relevance, the issue, and the challenges it poses, has been the subject of a significant level of research interest in recent years. This study therefore presents a state of the art review of current research relating to energy autonomy in sustainable communities and identifies a number of central issues which are regarded as being of critical importance. Demand Side Management is identified as one particular area in need of further research and development, along with the need for receptive social, political and regulatory environments.

© 2012 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author. Tel.: +44 141 548 3003; fax: +44 141 552 3997.
E-mail addresses: callum.rae@strath.ac.uk (C. Rae), fiona.bradley@strath.ac.uk (F. Bradley).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.08.002

1. Introduction

The threat of climate change combined with the continued depletion of fossil fuel reserves has, in recent decades, created a demand for a more efficient, sustainable energy supply model that lessens mankind's impact on the environment and promotes a less energy-intensive way of life. Satisfying this demand has presented a new challenge for the energy supply industry and requires the updating and renewal of well established energy systems which have been in place in some cases for the best part of a century. It has also created an opportunity for alternative and renewable sources of energy generation and has led to a significant increase in the deployment of renewable technologies in many countries, in the drive to reduce carbon emissions.

Recent years have seen low carbon and renewable energy systems successfully deployed at large scales, but in order to fulfil their considerable potential and meet ambitious carbon emissions reduction targets, these systems must also be applied at a smaller, localised scale. This represents a shift away from the historically dominant, large scale, centralised energy supply models towards a more distributed model, where energy is generated, stored and consumed locally. Locally embedded and distributed energy projects are now increasingly seen as a viable and preferable alternative to the traditional model and are capable of delivering benefits which range from increased security of supply for stakeholders to local economic benefits [1,2] as well as reduced environmental impact.

The constraints and disadvantages of centralised, fossil fuel based supply models have also gradually become apparent and have only served to incentivise this switch. One major contributing factor has been the recent increase in the price of the fossil fuel supply, which has been driven primarily by scarcity, but also by geo-political tension in resource-rich regions. This has counteracted the high costs of some low carbon and renewable technologies which are in some cases still technically immature. The production and installation costs of these technologies are expected to continue to drop as expertise and experience increases in conjunction with production efficiency, and improvements in economies of scale are developed [3]. The ability of distributed energy therefore to provide greater security and quality of supply should incentivise its use, as well as the financial incentives introduced by governments across the world to encourage the deployment of renewable energy technologies. The result of the above is an environmental, political, economic, technical and social environment in which locally generated and locally owned and managed energy is seen as being highly desirable.

This changing environment is having a profound impact on the way in which we view energy and is lessening the traditionally high degree of perceived separation between the typical consumer and the energy generation. The overall effect is the potential for a higher level of local energy autonomy, i.e., the ability of a community to function (and even prosper) without the need for energy imports. This approach to energy is therefore playing an important role in sustainable development at both the community and the regional level.

This paper reviews the research which has been conducted to date into the subject of energy autonomy in sustainable communities, in order to identify firstly the issues which are central to the topic, and secondly the areas where more research would be particularly beneficial or indeed essential in order to facilitate progress.

This review process has involved the collation of research from fields as disparate as renewable energy, politics, social behaviour and finance, and is described in more detail in Section 2. The research methodology adopted for this process is explained in Section 3, before Section 4 addresses some of the higher level, conceptual issues surrounding the concept of energy autonomy in sustainable communities, namely the scale and degree of energy autonomy. Section 5 examines some of the more technical issues involved, including energy storage and "demand side management" and the socio-economic and the policy issues associated with energy autonomy in sustainable communities are then addressed in Section 6. Finally, Section 7 looks at the prevalence of energy autonomy projects in island and remote communities, with a view to identifying lessons that can be learned from these existing examples.

2. Energy autonomy in sustainable communities

In order to develop a working understanding of the topic, it is prudent to define and examine the individual terms used within it.

2.1. Community

The word 'community' can be highly ambiguous, with many different definitions used. Definitions can vary broadly in terms of scale, and this can lead to a lack of clarity regarding the aims and scope of community projects [4] (this is discussed in more detail in Section 4). However, common themes are identifiable throughout many existing definitions, such as a sense of place, identity, localism and shared values.

Primarily a social term, a community (or a sense/feeling of community) tends to arise from the aforementioned shared values of those who populate it. Interestingly, Dalby and Mackenzie [5] explain how the formation of community identity often comes as a result of hardship or unifying resistance to an external threat to a shared environment, arguing that "the process of specifying threat is intrinsically also a process of specifying what is endangered".

Community scale can be thought of as highly appropriate when it comes to energy policy, and is seen as an appropriate scale at which to tackle many of the issues surrounding sustainability. This is reflected in the approach of numerous governments towards sustainable development, an example of which is the Department of Communities and Local Government in the UK [6]. The use of community scale development and policy also infers an emphasis on social issues rather than strictly technical or economic ones, and this reflects the importance of the social aspect of energy, and especially energy autonomy.

2.2. Sustainable communities

The term 'sustainable community' has become something of a 'buzz phrase' with regards to the built and social environment in

recent years. It tends to be applied to communities who promote or seek to promote sustainability in sectors such as water, food, transport, waste and energy and is applicable to either new or existing communities. Listed below are some of the characteristics and priorities, as defined by Geis and Kutzmark [7], which are typical of a sustainable community:

- Goals that are rooted in a respect for both the natural environment and human nature and that call for the use of technology in an appropriate way to serve both of these resources;
- The placement of high values on quality of life;
- Adoption of a systems approach to organisation and management;
- Supportive of life cycles;
- Responsive and proactive.

It is important at this point to acknowledge the holistic nature of the term 'sustainable community', and to recognise the importance of the high level of interconnectivity that exists between all aspects of sustainable development. However, the broad-ranging scope of the term requires narrowing for the purposes of this study, which will focus primarily on issues surrounding the supply of energy and its consumption. Given that energy supply and consumption is thought to contribute as much as 80% of the UK's carbon dioxide emissions – of which 40% can be attributed to the built environment [8] – this area of focus is seen as both appropriate and of significant importance.

2.3. Energy autonomy

The word autonomy primarily refers to the notion of self-governance, but also refers to independence, or "freedom from external control or influence" [9]. When applied to energy, autonomy can therefore be defined as the ability of an energy system to function (or have the ability to function) fully, without the need of external support in the form of energy imports through its own local energy generation, storage and distribution systems. This concept is also often referred to as energy self-sufficiency.

At the heart of this complex issue lie a number of basic but essential criteria that an energy system must exhibit in order to be deemed 'autonomous' for the purposes of this study:

- The energy system in question must be capable of producing sufficient quantities of energy so as to meet the demands of its population;
- The system provides energy storage to account for the temporal mismatch between demand and supply (particularly from renewable energy technologies);
- The system is capable of operating on a 'stand-alone' or 'off-grid' basis. The system may be grid-connected, but crucially it should be capable of functioning independently.

The primary benefits of energy autonomy include increased security of supply, the potential to reduce the cost of energy, and the ability to significantly reduce the carbon emissions associated with a community or region. There are also a range of secondary benefits that can result from an increased level of energy autonomy, such as local employment opportunities, the potential for financial reward through incentives or community ownership and increased independence [10,11].

3. Methodology

The literature review and analysis has been conducted with the aim of providing a wide and representative view of the key issues relating to the realisation of energy autonomy in sustainable communities.

The first part of the data collection process involved the use of various online keyword searches for academic journal articles, which enabled the identification of sources of both wide ranging and detailed information and expert knowledge on the subject. This data collection process exposed the author to broad ranging research issues and viewpoints on the subject, and enabled several key issues (details of which are given below) to be identified. These selected key issues were then individually researched in detail using the same process. This ensured that the literature review was sufficiently broad in scope as to ensure that adjacent research fields were also included.

This paper discusses the arguments, approaches, practices and research methods relating to each of these pivotal (and highly inter-related) issues, and evaluates current 'state of the art' research surrounding each issue and discusses the wider topic of energy autonomy in sustainable communities as a whole. The study concludes by identifying the areas that are in need of further research.

3.1. Identifying key issues

The key issues that have been selected are those that are seen as being central to the transition towards energy autonomous sustainable communities, or those which represent a significant barrier to energy autonomy or an area of untapped potential, such as an area of research focus with considerable scope for development.

Those issues which have been identified from the literature review conducted to date are central to the topic of energy autonomy in sustainable communities are summarised as follows:

1. The degree and scale of energy autonomy;
2. Matching demand with supply;
3. The importance of socio-economic and political factors;
4. Energy autonomy in island and remote communities;

The following sections discuss each of these issues in turn, explaining firstly the relevance of the issue before discussing the research focus placed on it in recent years. This therefore provides a state of the art review of all the pertinent issues associated with energy autonomy in sustainable communities.

4. The degree and scale energy autonomy

The scale of development is central to how energy autonomy is planned and measured and governs the design, construction, operation and future roll out of any sustainable community model. With changes in scale come changes in the number and range of stakeholders involved, the resources available and the decision making processes available.

As mentioned previously, the many and varied definitions of the word 'community' have given rise to a similarly diverse range of so-called community energy projects (this view is shared by Walker and Devine-Wright [4]) which serves to blur the definition of what constitutes a community energy project. This diversity of definition risks the loss of the underlying principles of sustainable community development and of energy autonomy.

4.1. The influence of scale on energy autonomy

In the case of autonomous energy systems, the definition/identification of boundaries is particularly important given their isolated nature, but there are a number of possible ways of defining them [12].

The relationship a defined system (in this case an energy system, which comprises both technical and social elements) has with other social/technical/economic/environmental systems outwith its own boundary is also important, and is likely to dictate the extent to which autonomy is sought.

The issue of scale in autonomous energy projects is one that is difficult to address, given the site-specific nature of each project. In both Sale [13] and Roseland [14], the concept of bioregionalism is identified as a means of addressing the issue, and is seen as being highly relevant particularly when it comes to sustainable community development. Bioregionalism is a way of viewing the world in naturally defined bioregions, which are seen as the optimal scale for human development. Defined by geographical features such as river basins or terrain characteristics such as topological or geological features, these bioregions provide natural boundaries, and place an emphasis on human dependency upon (and within) natural systems. Sale [13], describes bioregions as ''a place defined by its life forms, its topography and its biota, rather than by human dictates; a region governed by nature, not legislature.'' This concept has clear links to energy autonomy, as each bioregion needs to be capable of supporting its human inhabitants, or rather, human development must not reach an extent which cannot be supported by the bioregion in question.

4.2. The varying degrees of energy autonomy

The extent to which a sustainable community can be deemed energy autonomous depends primarily on the energy import/export capability of the system and the extent to which the community relies on outside expertise for the design, installation and maintenance of the energy systems used. Absolute autonomy in its purest sense can be considered as both theoretically and practically unachievable, as the design, manufacture, installation, commissioning, operation and maintenance of any energy system are all highly likely to require 'outside' expertise and facilities [15].

There are, however, varying degrees of autonomy that can be realistically achieved. These include being net energy 'neutral', whereby the community/energy system in question generates more energy locally than it consumes. Such a system may export the remainder to become 'energy negative'. Another option is 'stand-alone', where energy systems are capable of generating and storing enough energy to meet the needs of the entire community with no requirement for energy imports and minimal reliance on outside expertise, materials etc. However, as pointed out by Sartori et al. [12], there is currently little in the way of clear and regulated definitions when it comes to the use of terms such as 'zero carbon', 'zero energy' and 'net zero energy'. This is perhaps symptomatic of an industry sector that has emerged rapidly and is still developing at pace. This view is supported by Desta [16], which argues that the many different definitions of sustainability are based primarily on the relevant considerations of the groups that devise them and calls for a common, universal body of sustainability theory to allow a more focussed approach (this is echoed by Sinclair [17]). Hansson [15], however, argues that such a broad ranging and all-encompassing issue cannot easily be simplified, and its complications not knowingly escaped.

In many cases, it is likely that the extent to which a sustainable community achieves energy autonomy will be dictated by the scale and the degree of separation from surrounding communities and their associated resources. A street in a built up urban area, for example, is only likely to be capable of achieving a limited degree of autonomy as the motivations and benefits of doing so are unlikely to outweigh the financial and technological barriers that achieving it would present. A remote inhabited island, on the other hand, is likely to be able to achieve (or to *require* to achieve) a far greater degree of autonomy due to the fact that it is the most achievable and cost effective option of supplying energy to its inhabitants, and given the high degree of separation from the nearest established energy supply network. It should, however, be noted that such projects are still subject to the same (if not greater) barriers and costs as any other. The set of circumstances which have led island and remote communities to be identified as ideal candidates for energy autonomy will be discussed further in Section 7.

The case for energy autonomy is not, interestingly, universally supported. In Krajacic et al. [18], the energy costs associated with a 100% renewable energy supply scenario, (when applied via the H_2RES energy planning tool to island systems in Madeira, the Azores, Portugal and Croatia) were found to be far higher than current energy costs in the locations presented. Similar conclusions were also reached by Krajacic et al. [19] and Giatrakos et al. [20], which also examine the application of energy autonomy principles and the concept of 100% renewable energy supply. In Krajacic et al. [19], the increase in costs arose partly from the lack of energy export revenue, and partly from the extra supply infrastructure that had to be added to ensure security of supply.

4.3. Grid connected vs. stand alone

The benefits of grid interconnectivity are not limited to a community, regional or even national level, however. Recent years have seen the emergence of the concept of a European 'super-grid', designed to create increased levels of interconnectivity across the continent in order to allow pooling/sharing of energy resources on an international and continental scale [21]. The drivers behind this concept, i.e., the maximisation of renewable energy utilisation, enhanced security of supply etc, are the same as those for a community level, only at the extreme opposite end of the spectrum with regards to scale.

The literature reviewed in this study appears to suggest that from both financial and technical points of view, grid connection is beneficial. This is explained by Kaundinya et al. [22], which identifies a number of disadvantages to stand alone systems, such as the need to be able to run at low capacity factors, the high cost and technical uncertainty associated with energy storage and the possibility of having to 'dump' excess energy that cannot be stored. Also acknowledged is long-term economic viability, which play a large part in the decision to utilise grid connected or 'stand-alone' energy systems. However, should these barriers be removed or reduced in some way, then energy autonomy would be seen as a more favourable and worthwhile ambition, the advantages of which would be more likely to outweigh the disadvantages.

It therefore appears that whilst highly autonomous or 'stand-alone' type systems are a theoretically desirable goal, they can be an often expensive [19] but technically feasible solution. Grid connected systems with some degree of autonomy can bring a host of socio-economic benefits but ultimately, the highly context-specific nature of such projects means that the degree of autonomy targeted is likely to be dictated by local factors. This can be thought of as an 'appropriate' level of energy autonomy i.e., having as high a degree of autonomy as possible whilst balancing the possibility of unnecessary financial disadvantages with the benefits of increased energy autonomy. This has obvious parallels with Schumacher's notion of 'appropriate technology' [23] which presents the idea of locally owned and operated, energy efficient and environmentally friendly small scale technology as being best suited for both economic development and human well-being.

5. Matching demand with supply

The fundamental principle of matching energy supply with demand lies at the heart of even the most large/complex energy supply network. Central to the challenge of matching demand with supply are the temporal and magnitudinal mismatches that occur between demand and supply, which can be frequent and often unpredictable. This is illustrated in Fig. 1, which plots the energy output from a building mounted micro wind turbine and the energy demand profile of a small domestic UK property over a 48 h period.

There are two methods of tackling this challenge:

1. The use of energy storage systems which store excess energy when supply exceeds demand;
2. The use of demand side management and control (DSM) techniques to alter the characteristics of demand profiles to better suit that of the supply.

It should be noted that these two methods are not mutually exclusive, and are typically both used together to try and achieve the most efficient and effective solution. However, for the purposes of clarity, each area will be addressed separately.

5.1. Energy storage

Energy storage involves the capture and storage of energy when supply exceeds demand (surplus), for use when demand exceeds supply (deficit). It is of particular relevance when it comes to renewable energy, due to its ability to act as a buffer for energy generated by intermittent sources, thereby increasing the penetration and utilisation of renewable energy.

In cases where connection to a large energy distribution system is possible i.e., the National Grid or equivalent, this system can serve as a means of energy storage. However, in cases where such a connection is not possible (as in the case of islands and remote communities) on-site forms of energy storage are required to deal with the differences between demand and supply.

The choice of energy storage technology in autonomous energy systems (as in any other) is largely defined by a set of operational parameters and constraints which serve to make some storage technologies more suited to any particular given application than others [11]. Typical storage systems include:

- Batteries (including lead-acid, Na–S, Li–ion and flow batteries);
- Fuel cells;
- Pumped hydro storage;
- Flywheels;
- Compressed Air Energy Storage (CAES);
- Super capacitors.

Each of these storage methods is currently at a different level of technical maturity, which means that the more established technologies such as batteries and pumped hydro storage tend to be more widely used than those methods which have been developed more recently, such as fuel cells and super capacitors [24,25]. The various energy storage technologies listed above also vary considerably when it comes to installation and maintenance costs, operational lifetime, logistical and spatial requirements. They also vary in scale, with some technologies being better suited to some applications than others. For example, pumped hydro storage would be seen as a far more appropriate storage solution than batteries should the required capacity be several megawatts (MW), with the opposite being true if the capacity was several kilowatts (kW).

The development of storage technologies has been the subject of much research in recent years [11,20,24,26–29], [25], [30]. This is testament to the prominent role currently played by storage in distributed energy projects in general, and to its potential as a facilitator of cost-effective energy autonomy.

Despite the vital role played by energy storage in many autonomous energy supply systems (particularly off-grid systems) it is often seen as being prohibitively expensive and inefficient [26,27]. This is due in part to the unfavourable comparison that arises between a small scale energy storage system, and the ability of grid-connected systems to use the grid as a means of energy storage. For example; financial incentives may provide income for energy exported to the national grid, which itself is managed and maintained by external parties, whilst on-site, small scale energy storage represents a significant proportion of overall project cost. However, as is also acknowledged by Young et al. [26], there are certain scenarios and circumstances where typically prohibitively expensive storage technologies are preferential to grid connection i.e., in island or remote regions.

5.2. Demand side management

Despite the obvious importance of an informed selection of both energy supply and storage technologies, it is important to

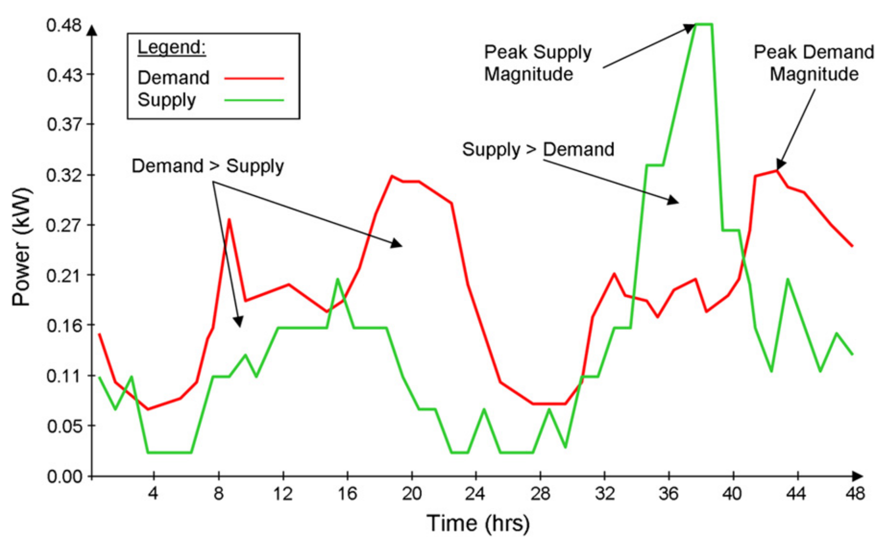

Fig. 1. Graph showing fluctuating demand and supply characteristics.

note that the need for both supply and storage is governed almost exclusively by energy *demand*. This describes the manner in which energy is consumed by the end user – be it industrial, commercial, domestic etc. – and can be seen as a function of building design, user behaviour and the building/community/region pattern of use. Demand is of particular relevance when considering autonomous energy systems, because whilst non-autonomous systems can rely on external energy generation or storage, autonomous ones must be capable of meeting energy demands without the need for external support. The inherent intermittency of most forms of renewable energy adds another layer of complexity to this challenge by creating often frequent and potentially highly disruptive temporal mismatches between supply and demand. By taking greater control over energy demand, it is possible to improve the match between energy demand and supply profiles, and gain more control over the system in general.

The process of manipulating energy demand is known as Demand Side Management (DSM), and involves the use of a range of techniques (illustrated in Fig. 2) with the aim of improving the match between supply and demand, and reducing overall energy demand.

The application of DSM has, until recently at least, focussed largely on the individual building/user scale. This has been for the intended benefit of both energy supply companies [31] including transmission network operators such as the National Grid in the UK in the form of demand stabilisation and system balancing, and customers via the resulting financial benefits that arise from reduced consumption levels [32]. Arguably the most attractive characteristic of DSM to utility companies and suppliers is its low cost when compared to the alternatives: infrastructure upgrades, development of new generation capacity etc.

However, it is the author's view that the greatest potential for the use of DSM lies in its ability to facilitate a transition to a more sustainable energy supply model by applying it to medium to micro scale renewable energy sources. This is a view that is shared by Pina et al. [33] and Blasques and Pinho [34], but is a topic which has only emerged recently [32]. The advantages that initially led energy utilities to pursue DSM – such as increased network flexibility/robustness, reduced need for back-up capacity and reduced overall consumption – are equally applicable (if not more so) in smaller autonomous energy systems, where the intermittent nature of renewable energy systems creates the need for considerable levels of energy storage.

Already, the use of DSM has been found to delay (or even in some cases remove) the need for new generation plant by increasing the utilisation of existing generation capacity [33,35,36]. This effectively increases the lifespan of the existing technologies, thereby improving their lifetime economic performance. Other benefits that can result from the effective use of DSM include increased overall system efficiency, greater system flexibility/robustness and the minimisation of storage requirements [37]. This could be particularly beneficial when it comes to unforeseen changes in demand such as those which could result from a change in building use or the expansion of a community.

Despite their benefits, the implementation of DSM techniques is likely to represent a significant challenge when it comes to their widespread and practical use. These difficulties are likely to arise from the limitations/intrusions that can result from the application of DSM, such as load shifting and the introduction (and enforcement) of energy consumption limits. These complexities are illustrated by Figueiredo and Martins [38], who outlines a method of combining building automation and DSM within a hybrid energy system, which includes energy storage. Crucially, this proposed methodology illustrates that DSM can be integrated into a hybrid system at a local/community level, in this instance via en energy metering system.

It is hoped that within the context of a sustainable community, where residents are aware of the need for DSM and its benefits, they will be more receptive, resulting in less resistance to the limitations and intrusions that may result from the use of DSM techniques. An example of this can be found on the island of Eigg in the Scottish Inner Hebridean islands, where residents are encouraged to limit their instantaneous consumption to 5 kW or lower, following the replacement of the islands many diesel generators with a hybrid renewable energy system [39]. Strengers [40] discusses the merits of a more social and psychological approach to demand, and presents DSM as a potential vehicle for positive behavioural change. It is argued that challenging the consumer perception of 'need' and 'requirement' can result in a more sustainable and informed relationship between the consumer and their energy use. This illustrates the importance of the social aspect of energy autonomy, and of sustainability in general, and serves to underline the importance of the role of the consumer in achieving sustainable goals such as reduced consumption and renewable generation, which is discussed in more detail in the following section.

Effective DSM techniques have been shown to be useful not just in terms of increasing levels of autonomy. Indeed, the benefits of DSM are applicable across all levels and scales of energy consumption and distribution. It is however the ability of such measures and techniques to increase the flexibility, robustness, longevity and utilisation of renewable/hybrid energy systems that are of particular interest in delivering high levels of autonomy to commuunities, due to the improvements in both economic and technical performance that can occur as a result. DSM is therefore seen as an area of considerable potential, and will be the subject of further research focus on the part of the authors.

6. The importance of socio-economic and political factors

As discussed previously, the transition to sustainable communities bridges a broad spectrum of engineering and technical disciplines. However, a technical shift in itself, whilst still crucial, does not guarantee the success of any sustainable community project [41]. As Scheer [42] argues in his book 'Energy Autonomy: the economic, social and technological case for renewable energy': "…energy autonomy is not just the outcome of a shift to renewable energy; it is, at the same time, the hard core of a practical strategy: autonomous initiatives by individuals, organizations, businesses, cities and states are required in order to get everything moving."

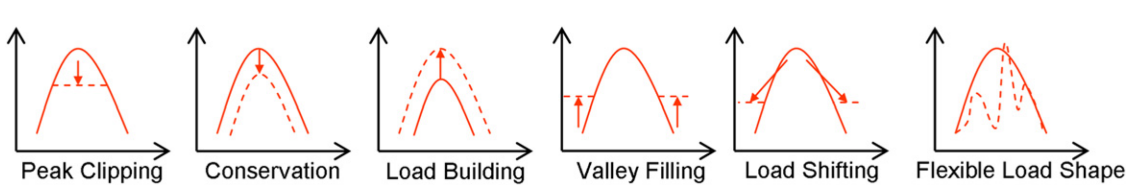

Fig. 2. The various DSM techniques, and their impact on demand profiles.

User performance can have just as great an impact on the success of a project as the performance of the buildings and energy systems which comprise it, and the need for positive interaction and stakeholder engagement is therefore a common theme throughout the literature [19,14,43–45].

6.1. The importance of human behaviour

Recent decades have seen an increase in public awareness of sustainability issues, with the responsibility – or rather, the ability to effect change – being increasingly passed down from large scale agencies such as government and industry towards the individual as the transition has progressed.

Improvements in building/community energy efficiency have seen the role of the user grow in importance [46]. As building design and regulations continue to strive towards higher energy efficiency and lower levels of energy consumption, the impact of energy wasting user behaviours on overall energy efficiency increases.

The process of influencing consumer behaviour when it comes to energy consumption is a complex one and while there are a number of behavioural change theories and models that attempt to make sense of this most complex issue, each differs in its focus, as explained by Moloney et al. [44]. These authors explain that the key distinction in the examination of these models is that which is made between 'internal' and 'external' variables. Internal variables are "those that influence or shape what goes on inside a person's mind, such as awareness, knowledge, values, attitudes, behaviour, rational thought processes, emotional states and entrenched habits". External variables are however "located in the physical, social and discursive environments in which a person lives".

A common theme in the literature is the need for education and understanding amongst the general public, as it is central to all methods of bringing about behavioural change. This view is supported in part by Schweiker and Shukuya [47], who argue that technological and behavioural improvements should go hand in hand, and demonstrate the effectiveness of user education as an effective carbon emissions reduction tool.

6.2. Community ownership and stakeholder engagement

Del Rio and Burguillo [2], stress the need to understand and analyse the social impacts that result from renewable energy deployment at a site-specific, local scale. Such impacts have an influence on public attitudes and perceptions of renewable energy and sustainability in general. These authors also highlight the need for those who contribute to and accommodate community energy projects to reap the financial and social benefits they can bring, such as job creation, financial rewards and improved security of supply. This appears to be a widely held stance which is almost universally supported in the literature [14,45,48].

In areas of mainland Europe, the concept of community ownership has proved successful at incentivising the use of medium to large scale wind energy installations. For instance, as much as 80% of Denmark's wind power capacity is owned by some sort of community partnership. This brings with it financial benefits, and has helped make Denmark a world leader in wind energy. It has also brought with it a host of additional benefits such as an increased sense of community and a more positive connection with renewable energy [49]. Community ownership models are therefore seen as useful way of providing not only technological change (backed by with financial incentives), but also of creating a more positive view of sustainability. This argument is supported by Warren and McFadyen [50], who found that local residents were less resistive to renewable energy development (in the form of wind turbines) if they knew that the local community was receiving some form of benefit.

The UK serves as a particularly effective demonstration of the need for stakeholder engagement, given the resistance to large scale renewable energy (particularly wind energy) that has arisen in recent years [51,52]. In fact, a direct correlation between community involvement and reduced resistance to wind energy was found by Warren and McFadyen [50], who found that whilst community involvement – in the form of ownership – does not transform negative attitudes into positive ones, it does appear to amplify positive attitudes and suppress negative ones. The benefits of increased community engagement and participation within a UK context are also discussed by Walker and Devine-Wright [4], Devine-Wright [53] and also by Rogers et al. [54], who used questionnaires and surveys in order to gauge the opinions and perceptions of various stakeholders. Their findings broadly support the idea that stakeholder engagement fosters more favourable local views of sustainability and renewable energy.

Public receptiveness to renewable energy has also been found to alter with scale. Research by Shamsuzzoha et al. [55] found public willingness for smaller local development to be approximately twice as high as willingness to accept large scale development. This appears to compound the need for stakeholder involvement and the sharing of the benefits between stakeholders.

6.3. The role of policy

Also included within the sphere of 'social factors' is the role of policy in facilitating increased energy autonomy. Roseland [14], Abu-Sharkh et al. [56] and Willis [57] all identify the need for significant changes to current energy planning and market regulation, in order to encourage the rollout of distributed energy projects and allow renewable energy to fulfil its considerable potential. Examples of successful use of policy to encourage renewable energy projects can be found across Europe, in countries such as Denmark, Sweden and Germany. These countries lead the way in terms of renewable energy – particularly in wind energy and the concept of community ownership – in the lead up to the turn of the century, thereby establishing themselves as world leaders by providing a supportive policy environment that allows the industry to flourish.

As noted by Hain et al. [58], existing UK government support networks (both financial and planning) tend to favour large schemes. Similarly, Walker et al. [59] examine UK renewable energy policy, and note the absence of a "strategic view…(of) what scales or types of projects should be supported". Instead, the authors describe the evolution of policy simply as a response to what is proposed at a community level. Perhaps more significantly, it could be argued that UK policy currently fails to address the issue of scale. This could be attributed to the desire of policy makers to avoid favouring any particular scale of development, and begs the question: is there a scale at which energy autonomy in sustainable communities can best be achieved?

The above findings suggest a correlation between the size of community energy projects being proposed/constructed and the size of the organisations behind them. Investment and support is given largely to those proactive organisations which actively seek it, which in the UK tends to be community groups, typically in the form of village/community groups and trusts. A good example of this is the village of Fintry in Scotland who, through the Fintry Development Trust, have sought to put sustainability at the centre of the village's image and the mindset of the residents. This has most notably been achieved through the successful negotiation for an additional turbine to be included in a nearby commercial wind farm development, which is owned by the trust. The income this turbine provides is then ploughed back into

community initiatives such as the provision of building insulation, the installation of micro-renewables and the planting of a village orchard [60]. The success of what has been achieved at Fintry has seen the village gain international notoriety, and effectively demonstrates the need for – and value of – stakeholder engagement [50].

Some authors have called for policy to become more proactive and less reactive, thus shifting the onus towards engaging a broader cross-section of society rather than depending on the proactive minority [61,62]. The literature reviewed also appears to widely favour a bottom-up approach to policy as opposed to a top-down approach, with Kellett [63] demonstrating the effectiveness of community-led initiatives over top-down policy mechanisms. Such mechanisms are described as being insufficient to bring about the changes to policy that are required. This view is shared by Rogers [54].

The view that increased levels of government support are required in order to allow community energy projects to fulfil their considerable potential is commonly held throughout much of the literature reviewed [14,49,57,64]. Bolinger [49] goes on to argue that UK policies such as the Non-Fossil Fuel Obligation (NFFO) have favoured larger projects led by wealthier and more established organisations instead of following the European model of community led co-operatives. Although UK policy has since undergone significant changes to better accommodate renewable energy (through, for example, the introduction of the Feed In Tariff), there is still a need for inclusive policy which promotes development at a range of scales, and for appropriate funding/ownership models.

6.4. *Economics and project finance*

The role of economics and project finance, as in any aspect of modern society, has a significant (arguably even decisive) impact when it comes to sustainable development and in particular renewable energy. Each renewable energy technology has performance and economic characteristics which make them suitable for some applications and unsuitable for others. This is clearly illustrated in Kaldellis et al. [11] where a range of energy storage technologies are subjected to techno-economic performance comparison at a number of scales. The high level of variation in cost and performance capability of these technologies can be seen as being strongly linked to the rate and extent of their deployment.

The cost of highly autonomous energy supply systems is both one of their main disadvantages and one of their main advantages. For example, the initial capital and installation costs of small scale renewable technologies are typically high in comparison to traditional, centralized energy supply in terms of, say, £/kW capacity installed. This concentration of cost at the outset of the system's operating life is very different to the conventional model, where (despite not insignificant plant costs) the lifetime cost of energy supply is more spread out, with the majority being spent on the fuel itself. This comparatively high initial cost can act as a barrier to the deployment of on-site renewables, but their financial competitiveness has improved in recent years, due largely to decreasing production costs and higher efficiencies when it comes to renewables, and increasing fuel costs when it comes to conventional fossil fuel use [3].

In many instances the lifetime cost of renewable energy technologies can be much lower than that of fossil fuelled equivalents (as discussed below in Section 7). It is in cases such as this, when the economic performance of renewable energy is seen as favourable, that the deployment of such systems occurs. Walker [64] cites difficulties to market entry and network connection barriers as additional financial disadvantages facing community energy projects, but acknowledges that steps have been taken recently by policy makers to address these difficulties, and goes on to predict an increase in community owned renewable energy projects over the coming years.

There are a number of financial incentives and support systems which have been introduced by various governments aiming to encourage the deployment of renewable energy. These range from grants for the purchase of renewables [65] to 'green' investment initiatives designed to encourage private-sector investment in renewable energy [66]. A particularly successful tool in this drive to encourage deployment is feed-in tariffs (FITs), which have been used in several countries [67]. FITs guarantee owners of small and micro-scale renewables a fixed price for the energy they produce. However, as is argued by Haas et al. [61], the promotion of renewable energy technologies through financial incentives alone is not enough to foster widespread deployment and behavioural change. To achieve these aims instead requires systemic change that includes the provision of training and education and also provides innovative and progressive regulatory institutions [57,61].

7. Energy autonomy in island and remote communities

As discussed previously, the subject of energy autonomy is the subject of increasing interest, and can be regarded as a highly attractive energy supply model, particularly at the community level. But given the extent and capacity of most existing power supply infrastructures, energy autonomy remains, for most communities in the developed world, a choice. However for some island and remote communities, reliance upon such infrastructure is not possible, and other means of energy supply must be considered.

7.1. *Conventional energy supply model*

Many island and remote communities are currently dependent on mainland/population centres for their energy supply, which often comes in the form of expensive (not to mention highly carbon intensive) fuel oil heating and diesel electricity generation [18,48]. This means that such communities are highly susceptible to energy price fluctuations and security of supply concerns. This has a knock-on effect on the cost of living and doing business in/with these communities.

In many cases, such as the Western and Northern Scottish isles, the conventional model has contributed to island depopulation, as younger generations are attracted to the mainland population centres by lower cost of living, improved employment prospects and earning potential. This in turn results in the 'greying' of the remaining population, and serves to weaken already disadvantaged and often out-dated island and rural economies, which often rely on subsistence farming and tourism [68].

The conventional energy supply model for island and remote communities can therefore be seen as being unsustainable, from a social, economic and environmental standpoint.

7.2. *Towards autonomous, renewable energy*

The emergence of autonomous renewable energy technologies as viable alternatives to the aforementioned conventional model have presented island and remote communities with the opportunity to pursue more sustainable, autonomous sources of energy by unlocking the often considerable natural resources at their disposal. Chief amongst these is the renewable energy resource that often exists in island and remote locations.

Due to their geographic features, islands such as the Western and Northern Scottish isles and the Aegean Greek islands for example, tend to have abundant renewable energy resources,

such as wind, tidal and solar. These resources are largely untapped under conventional, centralised energy models due to the high cost of interconnection with the mainland energy grid [18,26]. In order to utilise this often vast renewable resource under the conventional model, any existing island electricity infrastructure would require substantial (and therefore expensive) upgrading. This would typically include the provision of subsea high voltage cables linking the islands to the mainland which would have the capacity to carry power back to the mainland and to the national energy grid. This means that renewable energy resources can remain untapped, as the cost of utilising renewable energy resources at a large enough scale to benefit all (or most) of the island's inhabitants is not financially viable. It should be noted that another alternative to infrastructure upgrades lies in the use of Active Network Management, which seeks to optimise existing power networks and facilitate increased renewable energy deployment by using real-time control of both supply and demand [69]. However, this remains an emerging concept and few in-use examples exist.

In addition to the availability of abundant renewable energy resources, increased autonomy can also bring with it a host of benefits [10], including local employment opportunities, greater security of supply, the potential to attract investment/tourism and other economic benefits. These benefits further incentivise a switch to an autonomous, renewable energy supply system.

Arguably the most influential factor behind this switch is the potential for autonomous renewable energy systems to result in an increase in the cost of energy. Whilst the literature portrays this as a rare occurrence in existing examples [20], the potential for local generation to provide financial savings (thanks to efficient and effectively deployed renewables, and driven by escalating fossil fuel prices) is broadly acknowledged [26,11].

Despite the apparent benefits, there is a growing debate as to the merits of local scale energy deployment and its impact on the community. Del Rio and Burguillo [2] and Bain [70] both raise doubts as to the ability of local energy projects to provide the benefits that they are so often touted to bring. Bain refers to the 'local trap' as "the assumption that the local scale is inherently good and therefore advantageous" and points out that the concept of locally owned community energy is new and therefore relatively unknown. Instead, he suggests a cautious and critical approach to the exploration of resulting benefits and potential pitfalls.

7.3. Lessons for future energy autonomy projects

In many ways, the existing adoption of the underlying principles of sustainability and energy autonomy by some remote and island communities stems from the simple fact that they have the most to gain and the least to lose, i.e., they have the greatest motivation in doing so. Existing, successful examples can provide valuable lessons if and when the motivations of other areas of society reach a point where they too are sufficiently motivated to adopt a more autonomous and sustainable energy model. Island and remote communities also serve to support the argument that when the circumstances dictate, a shift towards a more autonomous and sustainable energy model is ultimately achievable.

From an academic perspective, there may be other reasons for the emergence of numerous remote/island-based studies. For example, the existence of clear and geographically defined boundaries that exist for island and off-grid energy systems means that other relevant system boundaries (be they social, economic or technical) can be clearly defined and measured, making for more easily obtainable and quantifiable results. Also, as identified in Hain et al. [58], remote (and in particular rural) community-level projects are ideal for the application of the principles of sustainable energy autonomy. This stems from the fact that they can be seen as having the most to gain, thanks in part to their need to diversify land use. This makes them ideal for onshore wind energy and the cultivation of biofuels. The authors also identify the receptive and often more knowledgeable approach towards renewable energy shown by rural communities as being another contributing factor, although there are of course exceptions to this generalisation [58]. As a result of both necessity and their clearly defined, often small-scale nature, these communities have acted as the testing ground for the methods, practices and technologies that could be used to facilitate a switch to a more autonomous energy model throughout the rest of wider society [48,26,11,20,71,28].

8. Conclusions

This study has presented a wide range of issues which are central to the development of higher levels of energy autonomy within sustainable communities. These issues have been shown to be highly inter-related and broad ranging, and this is representative of the holistic nature of sustainable development as a whole.

Whilst the generation and utilisation of renewable energy is primarily a technical challenge with economic and environmental motives, this study has shown that the social and political consequences of the increasingly prominent role of renewables in modern society cannot be ignored. It is clear that these areas can in fact play an important role in facilitating increased renewable energy deployment and maximising the benefits from doing so. The benefits of receptive social and political environments for renewable/autonomous energy projects are now much more clearly understood, and have been demonstrated at an international level.

Existing examples of autonomous energy projects in island and remote communities can provide a useful indication of the challenges and opportunities that are likely to arise from future projects in other areas of the built environment and indeed within society in general. These existing examples represent a highly useful resource when it comes to the design and development of technologies and techniques for new and future autonomous energy projects and the analysis of the impact of positive social engagement and community buy-in.

This study has shown that energy autonomy in sustainable communities, and the many issues it encompasses, has been the subject of significant and increasing levels of research and development in recent decades, as sustainability issues have risen higher up the public agenda. It has examined issues ranging from the role of energy storage technologies through to public attitudes towards local energy generation, and has also discussed some of the financial incentives as well as the role of policy in facilitating the delivery of energy autonomy. It has also identified some areas for potential further examination which appear to have received relatively less attention to date. The potential for utilising Demand Side Management and control, for example, in facilitating greater energy autonomy does not appear to have been fully explored at present, as energy generating technologies and, albeit to a lesser extent, storage technologies have both received more attention in terms of research focus within recent years. There is therefore a need to investigate the ability of Demand Side Management (DSM) to facilitate and improve energy autonomy in sustainable communities in greater detail and to examine its social, economic and environmental impact.

Acknowledgements

The authors wish to thank the Engineering and Physical Sciences Research Council for funding the work and Laura Kane for her assistance with proof-reading.

References

[1] Chicco G, Mancarella P. Distributed multi-generation: a comprehensive view. Renewable and Sustainable Energy Reviews 2009;13(3):535–51.
[2] del Rio P, Burguillo M. An empirical analysis of the impact of renewable energy deployment on local sustainability. Renewable and Sustainable Energy Reviews 2008;13(6-7):1314–25.
[3] Arent DJ, Wise A, Gelman R. The status and prospects of renewable energy for combating global warming. Energy Economics 2011;33(4):584–93.
[4] Walker G, Devine-Wright P. Community renewable energy: what should it mean? Energy Policy 2008;36(2):497–500.
[5] Dalby S, Mackenzie F. Reconceptualising local community: environment, identity and threat. Area 1997;29(2):99–108.
[6] DCLG, What we do, D.o.C.a.L. Government, editor. 2012.
[7] Geis, D and T Kutzmark, Developing sustainable communities the future is now. 1998.
[8] DECC, DECC science and innovation strategy 2012, D.o.E.C. Change, editor. 2012, Crown Publishing.
[9] Dictionary OE. Autonomy. Oxford University Press; 2012.
[10] Muller MO, et al. Energy autarky: a conceptual framework for sustainable regional development. Energy Policy 2011;39(10):5800–10.
[11] Kaldellis JK, Zafirakis D, Kavadias K. Techno-economic comparison of energy storage systems for island autonomous electrical networks. Renewable and Sustainable Energy Reviews 2009;13(2):378–92.
[12] Sartori I, Napolitano A, Voss K. Net zero energy buildings: a consistent definition framework. Energy and Buildings 2012;48(0):220–32.
[13] Sale K. Dwellers in the land: the bioregional vision. Univ of Georgia Pr; 2000.
[14] Roseland M. Sustainable community development: integrating environmental, economic, and social objectives. Progress in Planning 2000;54(2):73–132.
[15] Hansson SO. Technology and the notion of sustainability. Technology in Society 2010;32(4):274–9.
[16] Desta M. Sustainability and sustainable development: historical and conceptual review. Environmental Impact Assessment Review 1998;18(6):493–520.
[17] Sinclair P. Describing the elephant: a framework for supporting sustainable development processes. Renewable and Sustainable Energy Reviews 2011;15(6):2990–8.
[18] Krajacic G, Duic N, Carvalho MdG. H2RES, Energy planning tool for island energy systems—the case of the Island of Mljet. International Journal of Hydrogen Energy 2009;34(16):7015–26.
[19] Krajacic G, et al. Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO_2 emissions reduction. Applied Thermal Engineering 2011;31(13):2073–83.
[20] Giatrakos GP, et al. Sustainable energy planning based on a stand-alone hybrid renewableenergy/hydrogen power system: application in Karpathos island, Greece. Renewable Energy 2009;34(12):2562–70.
[21] De Decker J, Woyte A. Review of the various proposals for the European offshore grid. Renewable Energy 2012 0.
[22] Kaundinya DP, Balachandra P, Ravindranath NH. Grid-connected versus stand-alone energy systems for decentralized power—a review of literature. Renewable and Sustainable Energy Reviews 2009;13:2041–8.
[23] Schumacher EF. Small is beautiful: a study of economics as if people mattered. ABACUS ed. London: Sphere Books Ltd; 1973.
[24] Hadjipaschalis I, Poullikkas A, Efthimiou V. Overview of current and future energy storage technologies for electric power applications. Renewable and Sustainable Energy Reviews 2009;13(6â€"7):1513–22.
[25] Chen H, et al. Progress in electrical energy storage system: a critical review. Progress in Natural Science 2009;19(3):291–312.
[26] Young DC, Mill GA, Wall R. Feasibility of renewable energy storage using hydrogen in remote communities in Bhutan. International Journal of Hydrogen Energy 2007;32(8):997–1009.
[27] Ren L, et al. Techno-economic evaluation of hybrid energy storage technologies for a solar-wind generation system. Physica C: Superconductivity 2012 0.
[28] Chen F, et al. Renewislands-renewable energy solutions for islands. Renewable and Sustainable Energy Reviews 2007;11(8):1888–902.
[29] Nair N-KC, Garimella N. Battery energy storage systems: assessment for small-scale renewable energy integration. Energy and Buildings 2010;42(11): 2124–30.
[30] Zoulias EI, Lymberopoulos N. Techno-economic analysis of the integration of hydrogen energy technologies in renewable energy-based stand-alone power systems. Renewable Energy 2007;32(4):680–96.
[31] Berry L. A review of the market penetration of US residential and commercial demand-side management programmes. Energy Policy 1993;21(1):53–67.
[32] Hong, J, The development, implementation, and application of demand side management and control (DSM+c) algorithm for integrating micro-generation system within built environment, in energy systems unit, department of mechanical engineering. 2009, University of Strathclyde: Glasgow. p. 273.
[33] Pina A, Silva C, Ferrao P. The impact of demand side management strategies in the penetration of renewable electricity. Energy 2012;41(1):128–37.
[34] Blasques LCM, Pinho JT. Metering systems and demand-side management models applied to hybrid renewable energy systems in micro-grid configuration. Energy Policy 2012;45(0):721–9.
[35] Moura PS, de Almeida AT. Multi-objective optimization of a mixed renewable system with demand-side management. Renewable and Sustainable Energy Reviews 2010;14(5):1461–8.
[36] Kelly A, Marvin S. Demand-side management in the electricity sector: implications for town planning in the UK. Land Use Policy 1995;12(3):205–21.
[37] Ribeiro LAdS, et al. Making isolated renewable energy systems more reliable. Renewable Energy 2012;45(0):221–31.
[38] Figueiredo J, Martins J. Energy production system management–renewable energy power supply integration with building automation system. Energy Conversion and Management 2010;51(6):1120–6.
[39] islandsgoinggreen.org, 5 kW Challenge. 〈http://www.islandsgoinggreen.org/about/eigg-electric/5kw-challenge/〉 accessed: 22nd January 2012.
[40] Strengers Y. Peak electricity demand and social practice theories: reframing the role of change agents in the energy sector. Energy Policy 2012;44(0): 226–34.
[41] Schweizer-Ries P. Energy sustainable communities: environmental psychological investigations. Energy Policy 2008;36(11):4126–35.
[42] Scheer H. Energy autonomy: the economic, social and technological case for renewable energy. Earthscan/James & James; 2007.
[43] Mendes G, Ioakimidis C, Ferrao P. On the planning and analysis of integrated community energy systems: a review and survey of available tools. Renewable and Sustainable Energy Reviews 2011.
[44] Moloney S, Horne RE, Fien J. Transitioning to low carbon communities-from behaviour change to systemic change: lessons from Australia. Energy Policy 2009;38(12):7614–23.
[45] Kaplan S. New ways to promote proenvironmental behavior: human nature and environmentally responsible behavior. Journal of Social Issues 2000;56(3): 491–508.
[46] Pilkington B, Roach R, Perkins J. Relative benefits of technology and occupant behaviour in moving towards a more energy efficient, sustainable housing paradigm. Energy Policy 2011;39(9):4962–70.
[47] Schweiker M, Shukuya M. Comparative effects of building envelope improvements and occupant behavioural changes on the exergy consumption for heating and cooling. Energy Policy 2010;38(6):2976–86.
[48] Michalena E, Angeon V. Local challenges in the promotion of renewable energy sources: the case of crete. Energy Policy 2009;37(5):2018–26.
[49] Bolinger, M, Community wind power ownership schemes in Europe and their relevance to the United States. 2001.
[50] Warren CR, McFadyen M. Does community ownership affect public attitudes to wind energy? a case study from south-west Scotland Land Use Policy 2010;27(2):204–13.
[51] Jones CR, Richard Eiser J. Understanding 'local' opposition to wind development in the UK: how big is a backyard? Energy Policy 2010;38(6):3106–17.
[52] Cass N, Walker G. Emotion and rationality: the characterisation and evaluation of opposition to renewable energy projects. Emotion, Space and Society 2009;2(1):62–9.
[53] Devine-Wright P. Local aspects of UK renewable energy development: exploring public beliefs and policy implications. Local Environment 2005;10(1):57–69.
[54] Rogers JC, et al. Public perceptions of opportunities for community-based renewable energy projects. Energy Policy 2008;36(11):4217–26.
[55] Shamsuzzoha A, Grant A, Clarke J. Implementation of renewable energy in Scottish rural area: a social study. Renewable and Sustainable Energy Reviews 2011.
[56] Abu-Sharkh S, et al. Can microgrids make a major contribution to UK energy supply? Renewable and Sustainable Energy Reviews 2006;10(2):78–127.
[57] Willis R. Grid 2.0: the next generation. London: Green Alliance; 2006.
[58] Hain JJ, et al. Additional renewable energy growth through small-scale community orientated energy policies. Energy Policy 2005;33(9):1199–212.
[59] Walker G, et al. Harnessing community energies: explaining and evaluating community-based localism in renewable energy policy in the UK. Global Environmental Politics 2007;7(2):64–82.
[60] fintrydt.org.uk, Fintry Development Trust.
[61] Haas R, et al. How to promote renewable energy systems successfully and effectively. Energy Policy 2004;32(6):833–9.
[62] Jackson, T and G Surrey, Motivating Sustainable Consumption. 2005.
[63] Kellett J. Community-based energy policy: a practical approach to carbon reduction. Journal of Environmental Planning and Management 2007;50(3): 381–96.
[64] Walker G. What are the barriers and incentives for community-owned means of energy production and use? Energy Policy 2008;36(12):4401–5.
[65] BRE, Grant schemes for low carbon and renewable energy systems installation. 〈http://www.bre.co.uk/page.jsp?id=1332〉 accessed: 11th May 2012.
[66] bis.gov.uk, UK Green Investment Bank. 〈http://www.bis.gov.uk/greeninvestmentbank〉 accessed: 18th May 2012.
[67] Couture T, Gagnon Y. An analysis of feed-in tariff remuneration models: implications for renewable energy investment. Energy Policy 2010;38(2): 955–65.
[68] Caird JB. Changes in the highlands and Islands of Scotland 1951–1971. Geoforum 1972;3(4):5–36.
[69] Currie RAF, et al. Smarter ways to provide grid connections for renewable generators. Institute of Electrical and Electronics Engineers 2010.
[70] Bain C. Local ownership of ethanol plants: what are the effects on communities? Biomass and Bioenergy 2011;35(4):1400–7.
[71] Indradip M. A renewable island life: electricity from renewables on small islands. Refocus 2006;7(6):38–41.